**Technology of Surface Coating**
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**Lecture 25**
**Coating of Monolayer Abrasive Grain by Wetting**

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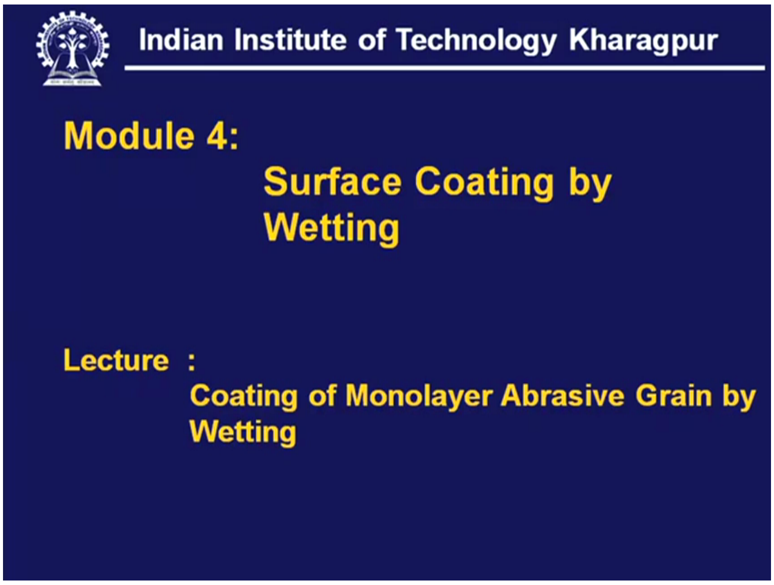


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Coating of monolayer abrasive grain by wetting. Now exactly what we mean? That a surface which can be a metal, alloy or even a ceramic that can be coated with one abrasive grain having a monolayer configuration.

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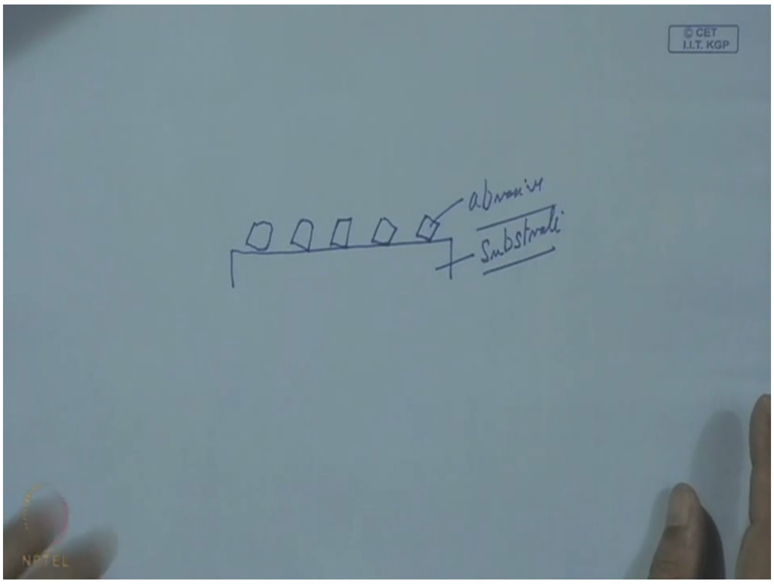


This can be illustrated by sketch, if this is the substrate on which the abrasive grain can rest they can be anchored or fixed or bonded in the form of a monolayer. Now here comes the question how we are fixing these grains on the substrate and that is the bonding technique and the bonding material which are being used and at the same time this is not a continuous layer of abrasive that means there is a gap in between and it is intentionally done to have some of the desired effect from this vertical product.

And this is exactly what we mean as a monolayer configuration and this monolayer configuration that is being supported by one substrate. So these are actually abrasive article and this is the substrate. Now where we can use such a product that will be of immediate interest?

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Now here we see that application of abrasive, it has a widespread application in the area of Manufacturing. So this abrasive can be used in a grinding wheel, it can be used as loose abrasive in the lapping process, it can be even honing process or it can be what we know as coated abrasive that means in a belt grinder, one endless belt that is actually coated a medium that means the medium of the belt that is coated with a layer of abrasive and in this case it is actually glued and this is also a single layer formation.

But what we mean? As we have presented here this is actually the bonding of these abrasives in a monolayer configuration, in particular it is going to be a metal or one alloy substrate material.

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Now bonded abrasive and conventional bonding material, now this is actually what we mean? It is actually the grinding wheel or the abrasive tool and as we know that there are basically 3 types of bond material one is resin, the second one is metal and the third one is vitreous bond and this recall conventional bond that means this is a conventional way of working with these bonds, so that this bond and the abrasive together can make an abrasive mass which can be of end-use just like one abrasive tool or one grinding wheel and here this abrasive can be conventional abrasive or it can be super abrasive.

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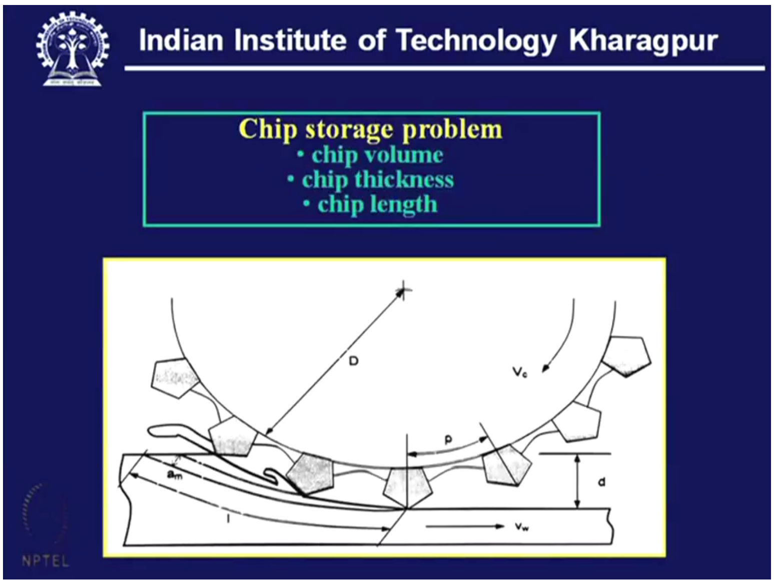

Conventional abrasive means aluminium oxide or silicon Carbide and whereas super abrasive means it is diamond or cubic boron nitride. Now what we find here? The requirement on the abrasive tool, the requirement of the abrasive tool this is actually what we find? In fact if we see this is just a circular wheel which is a rotary in nature and here we have the grit materials. Now these great materials are bonded and this is one ideal situation that means we have some spacing than the (()) (5:13) of the grit tip above the bond.

So these are some of the specification of the wheel and this thing cannot be independently chosen. What we mean here? This protrusion of the tip above the bond and this spacing they have some kind of relation with the chip storage volume that means this grit protrusion and the spacing when we put them together they make actually the chip storage volume that means the chip space for easy disposal and evacuation of the chip.

However what is mean by Chip volume? That Chip volume also depends upon the thickness of the chip which is varying from 0 and which attains its highest value, once the grit is about to leave the work piece, so it starts with 0 it assumes the maximum value here and if we consider this arc of contact and here this is the wheel dept of cut.

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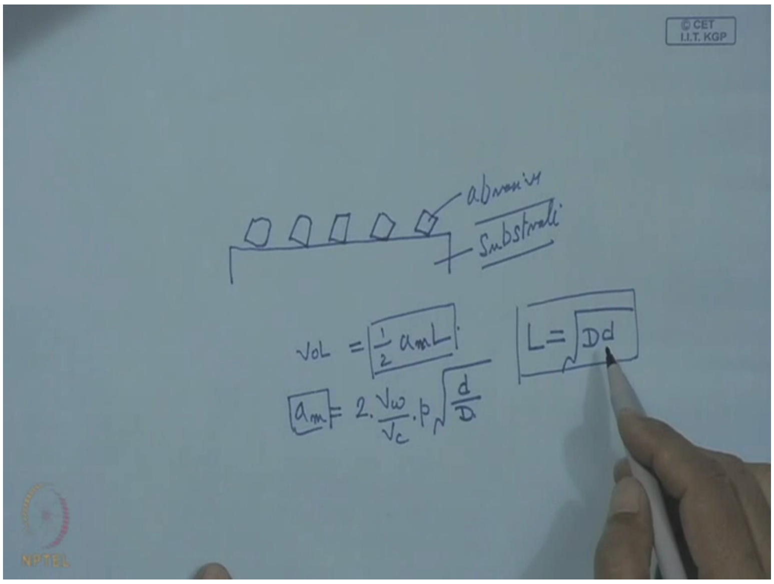

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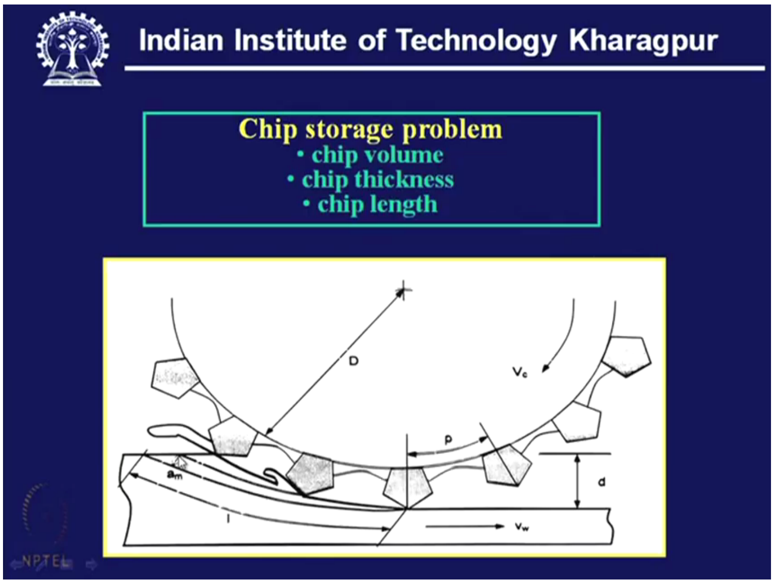


Now wheel depth of cut is quite small compared to the diameter of the wheel and in that practical purpose, what we find? The volume of the material removed by each grit that means this grit starts its actions from this point and that is the kind of this grinding action it repeats itself, however there will be series of this grit arranged over the entire periphery and each has its own cutting action and the volume of the chip that will be given by am into L, this is one thing.

Then this (am) value it is also possible to find out is given by Vw by Vc into p into root over small d by capital D. So Vw that is one operational parameter, Vc that is peripheral speed of the wheel, Vw that is the worktable speed, small d that is the wheel depth of cut and capital D that is the diameter of the wheel. So from there we can determine (am) and what is L? That is the length of the contact and this can be very well approximated by root over capital d into small d.

So from all these we are in a position to determine what will be the name of the chip? Now the problem begins from that point when we like to use this wheel just not as a grinding wheel but as a wheel for super abrasive machining that is high-speed using one of the best grit material from the diamond family or from the cBN family. So it is not the problem with the grit material either it is a problem alone of the bond material but it is a question of what is the protrusion of this grit?

Which we can maintain above the bond and how, with what uniformity these grits can be placed over the entire periphery? And this is actually one plane of the wheel and this has a back engagement that means normal to this picture we have what we call width of cut, so what we see here? That it is mostly the chip storage problem that becomes the major issue rather than the cutting capability of the grit or the strength of the bond.

So the problem here is, in summary it is the chip disposable problem or chip storage problem and is a consequence of this could be that this space cannot accommodate this volume of the chip which is being produced and by entire space will be filled in and then that will be squeezed between this job work piece on one side and that is the bond material on the other side and the 2 grits one is following the other.

So this is actually the confined volume where if it is not adequate then the whole chip will be squeezed over the surface and the constraints are given here either by this volume of the chip or by length of the chip. Length of the chip also very much comes in picture because of the simple reason; this length should be adequate to accommodate the length of the chip.

It is of course uncut length which will be reduced little bit but one thing also should be kept in mind that when we have larger arc of contact particularly with a large diameter wheel and also large depth of cut, in that case the length will be sizeably large. It will be sufficiently large and if we don’t provide adequate length between the 2 crystals there will be folding back it will be like a coiling.

And this coil can also have some squeezing effect in this volume available between the bond and this arc of contact and these 2 grits which are one is following the other. So this is one of the major issues, as we consider grinding and transformation of that grinding to abrasive machining involving high-speed and also high material removal rate there comes the question of Chief disposal or chief evacuation.

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Now considering this aspect we see that there are some limitations, serious limitations with this present state of the art. Apart from this chip storage problem what we can see? The complexity of manufacturing route. We start this when we use this abrasive grit with either resin, metal or vitreous bond than it is mostly the conventional way of working that means we need a mould, without this mould we cannot give the shape of the wheel.

So it can be cylindrical, it can be cup shaped, it can have some bevelling, it can have a V form, it can be a small wheel, very large wheel whatever may be the case, we need a mould and this mould shape is important in that, that will give us the final form or the geometrical form on the wheel and when it is a complicated form then it will become rather difficult to transfer this geometry from that mould to that actual piece.

And also the flexibility of making the wheel of any shape that also becomes a questionable issue that how flexible the process is when the demand for variety of geometry is so high. Now as a solution to this problem we have another kind of wheel, it is a different concept, it is no more a solid mass. As we see in a conventional wheel, it is a solid mass which is moulded in a cavity and then it has to go through all the process.

So it is a mould, it is a green moulding then sintering or firing then follow-up processes before grinding, we must go through this follow-up process which is truing, dressing and grit conditioning. So these 3 processes the wheel must go through before it becomes one of the efficient grinding wheel for this particular grinding action.

Now this truing, dressing or grit conditioning it maybe not that difficult task when it is a conventional abrasive what we mean? Aluminium oxide or silicon Carbide then this truing, dressing and grit conditioning can be well handled and managed but when it becomes diamond or cBN then this follow-up process after this firing a sintering this is not so easy, it is very delicate and difficult task to carry forward this truing, dressing and grit conditioning.

So considering 2 issues or problems, one is chip storage problem another is the flexibility in manufacturing the wheel which can be used with a particular shape where the manufacturing itself is a flexible process plus the material plus the profile of the grit or the profile of the grinding wheel is prepared in that it can take up heavy grinding that means high remove material removal red grinding or what we call stock removal grinding.

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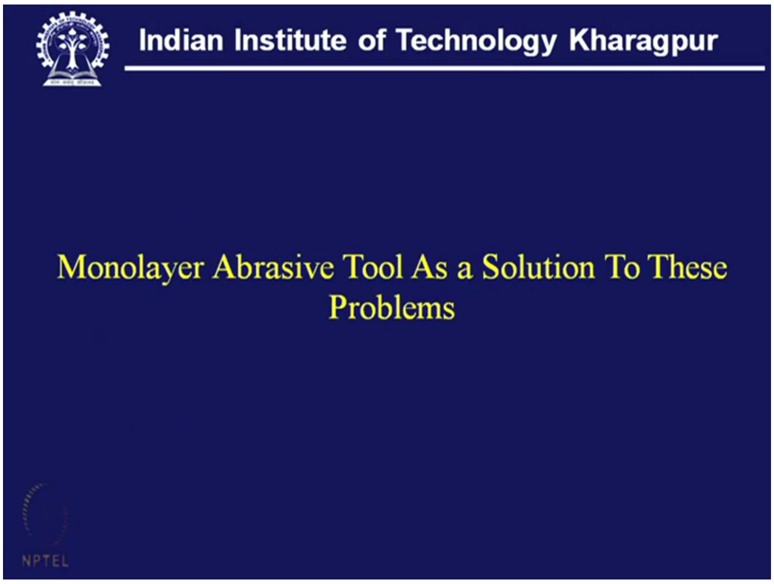

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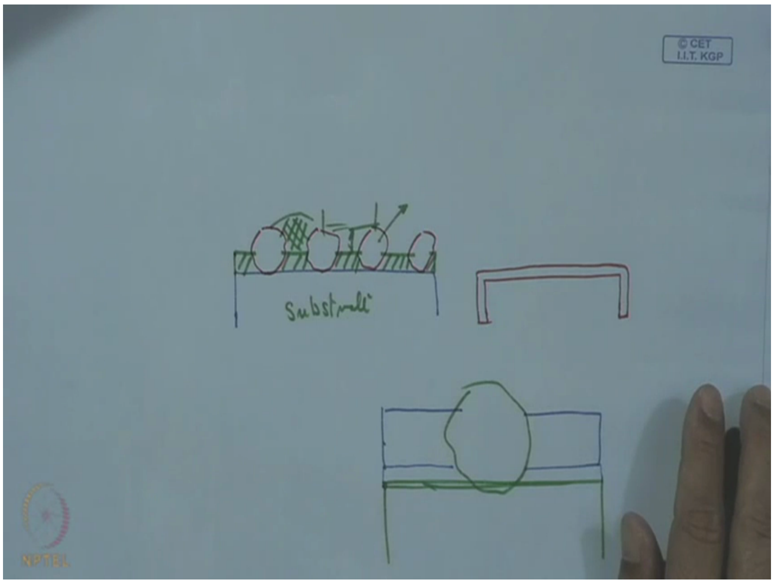


And for that we have a new concept and that is exactly what we call? Monolayer abrasive tool and it is going to offer a solution to this aforesaid problem. So monolayer abrasive tool basically what we see here? That as we have mentioned at the very beginning of this discussion that means on a substrate it can be say for example this is metal substrate and over that we have the grits.

So this is just like one layer formation, one way it is very similar to a coated tool where on high-speed steel or a carbide tool we put a coating and the life, service life of the tool depends upon the survival of this coating. Similarly, so it is just not a tool with composite structure that means regrinding or re-sharpening of this tool is not just possible once coating fills, we also can say that leads that is the failure of the tool.

Similarly here this one layer of grit that is supposed to work for a reasonable period of time and it is not even a composite structure. In a composite structure of conventional wheel the first top layer becomes dull or becomes flatten obviously the truing or dressing operation comes in picture and that removes the dull layer, so that one layer from behind that can appear and that becomes the active layer of the abrasive.

But when we set one layer of grit than this whole performance of this wheel that depends upon this retention of this one layer on this surface. So here of course, we must have some kind of bonding agent and also the technique of bonding. So this is the substrate that means the basic material and that we have this bonding agent. Various ways it can be done, so this is the bonding agent.

Now question is, whether such a bonding agent and a bonding technique we can really bring up a tool, ideal tool which can be given any shape according to the grit of the grinding and at the same time we can also provide adequate space in between the crystal and the space above the bond, so that adequate space is available for easy clearance chip removal and at the same time this wheel can be used with high material removal rate even under dry cutting without any support of lubricant or some coolant.

And at the same time the most important thing is that this grit should not pull out or get dislodged then that is one of the issue that means what will be the level of coverage if this is the grit? So one would be interested to know that if we consider just one single grit being resting on a metal support and to what extent we have to put this layer whether this is as low as 10 to 20 percent or it should be as high as 70 percent that is the issue and on that the success of this bonding material and the bonding technique will depend.

Because ultimately the whole aim of this work is to bring up a tool or an abrading surface which provides adequate clearance space, obviously that means low bond coverage but at the same time without the risk of fallout of the grit. So these are to be met by using a particular bonding technique and a bonding material.

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Now comes the question which has been raised, how to manufacture monolayer abrasive tool? There are actually 2 technology for making such thing, one we called Electroplating technology another is Active Brazing technology. So these are the 2 available processes which can be used for making such configuration that means the abrasive grit that monolayer consideration.

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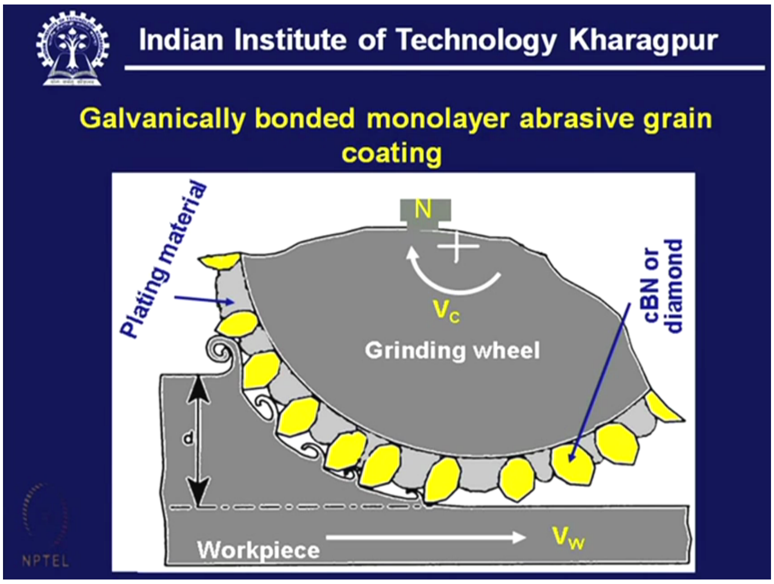


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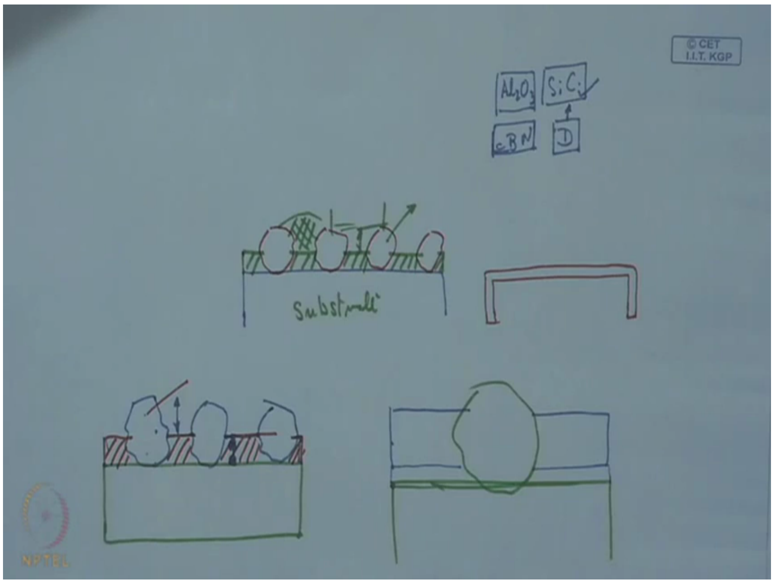


Now here what we see? That this is just a schematic representation of this wheel where it can be cBN or diamond. Now why do we prefer in single layer configuration cBN or diamond? The reason is obvious; the choice is obvious that means here if this is the metal support which is the base for holding the grit and these are the grits and there is a bonding material.

So that is the substrate this is the bonding material and these are the abrasive grit. Now the whole life of the tool depends also on the quality of abrasive or wear resistance of the abrasive that means it's retention of the hardness, resistance to plastic deformation then thermal stability, chemical civility all this issue should be taken into consideration and this will wear out with passage of time.

That means if we consider that this is the limiting bond level we cannot go below that point that is the critical thickness of the bonding layer then from this point to this point that is actually the zone over which these grit is expected to work efficiently. So this is actually the rate of work which will determine the service life of this grit.

Now wear from this point very close to this bond level and in that we know that aluminium oxide or silicon Carbide they are not that wear resisting in comparison to cBN or diamond. So where we use normally silicon Carbide as conventional abrasive, now if it will be it has to be replaced by a super abrasive than the choice is diamond. Similarly most of the cases if aluminium oxide being the conventional abrasive is to be substituted for by cBN.

Substituted for by super abrasive than it becomes cBN and diamond one that can be equivalent to few hundreds of layer of grains of aluminium oxide or silicon Carbide. So grinding ratio, if we consider the grinding ratio of CB and to AL2O3 it can be few hundred the ratio that means wear volume of aluminium oxide will be few hundred times compared to the wear value of cBN.

So from there we come to immediate conclusion that it should be cBN or diamond those are the best candidates for this single layer tool. So here what we see? That with this galvanic tool though it is better, much better compared to the conventional wheel that means where we need this moulding technology. However the question is that to hold this grit in place that fallout should not be allowed dislodgement.

So it is also our common experience that for holding this grit in place with this layer, this is the electro plated layer or galvanic layer and which is in most of the cases nickel or in electroless plating we also use nickel phosphite and that has to be raised at least two third or 70 percent for holding this. So though we get 30 percent but still considering the requirement of grinding and lot of high expectation still this doesn't give us the best possible solution for solving this problem of grit holding capability of the bond or creation of the chip space.

So if we consider these issues then we must look for a better process though we understand that this is a wheel which can show marked improvement over the conventional wheel where it is a question of high material removal rate number 1 and number 2 when we need the wheel of different geometry in short notice.

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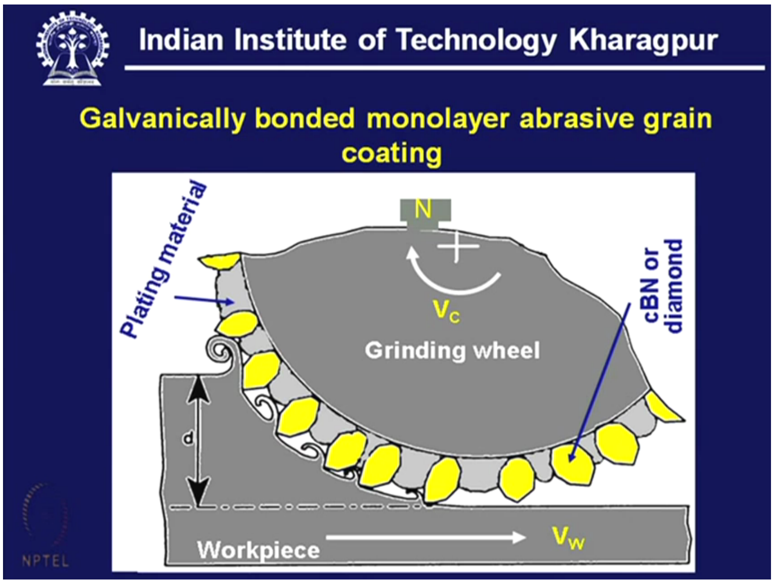


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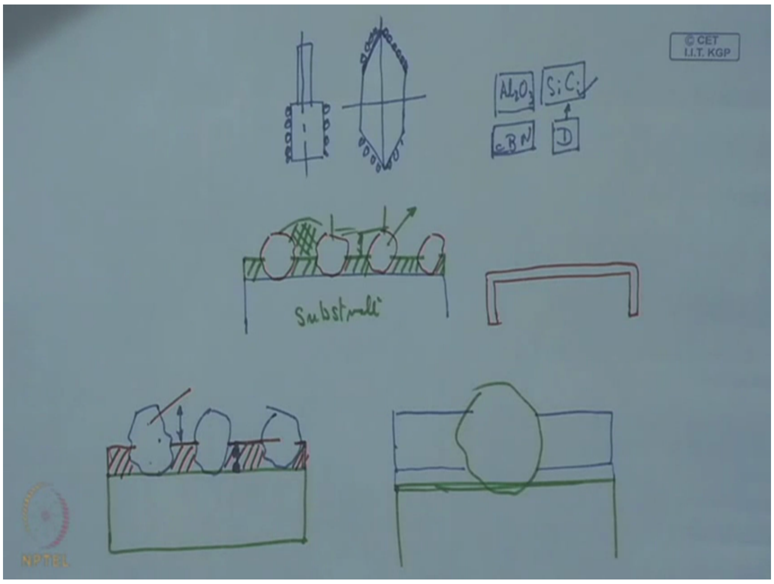


The idea is that in this case what we need? We just need a pre-form. A pre-form it can be any shape, so it can be machine with by precision machining and over that this grit can be anchored by this electroplating technique. So only the pre-form is necessary and we can do away with this moulding or the requirement of the moulding. So that is one of the greatest advantages of this technology.

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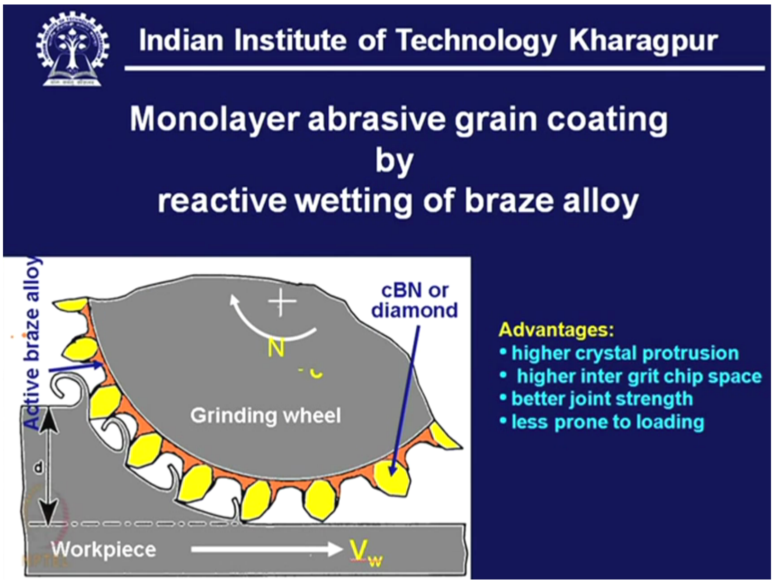


Now this limitation of galvanically monolayer abrasive wheel which has been just now highlighted because it is at least 70 percent coverage that can be reduced to 20 to 30 percent coverage by this brazing technique, so what we're doing here? We are not changing neither this material this core, core area of the wheel which is steel special steel according to the need of grinding also the same grit material it remains as it is.

But what we are changing here? It is mostly the bonding material and the bonding technique. So one can easily compare this bond level which is quite high and that can be reduced here and interesting part is that, this is done by this reactive wetting. So this term is very important reactive wetting of braze alloy or the bonding alloy and this because of this wetting, if we can achieve good wetting we get a concave surface whereas in the previous case it was like a convex.

So at the root, here we have less coverage and in between we have high rise of the bond we can compare this, here we have larger thickness and because it is nonwettable, wetting is not that good and so here it is like a convex, very typical of not wetting character but here it is wetting character. So what we need in between? We need low bond coverage that means high clearance.

And on along this side of this grit, what we need? That material should be pulled up by lowering this interfacial tension. So that spontaneously there will be, the material will climb up and giving this necessary support on the 2 sides of the grit and as this one each grit is participating there will be grinding force and in that case this chip which is coming out it has larger space for easy accommodation.

There will be less chances of wheel loading or squeezing and the wheel offers free cutting even under dry condition not only that because of this large grit protrusion from this point to this point the service life of this cutting point will be longer in comparison to what we find in this case. In this case this will be only the protrusion available.

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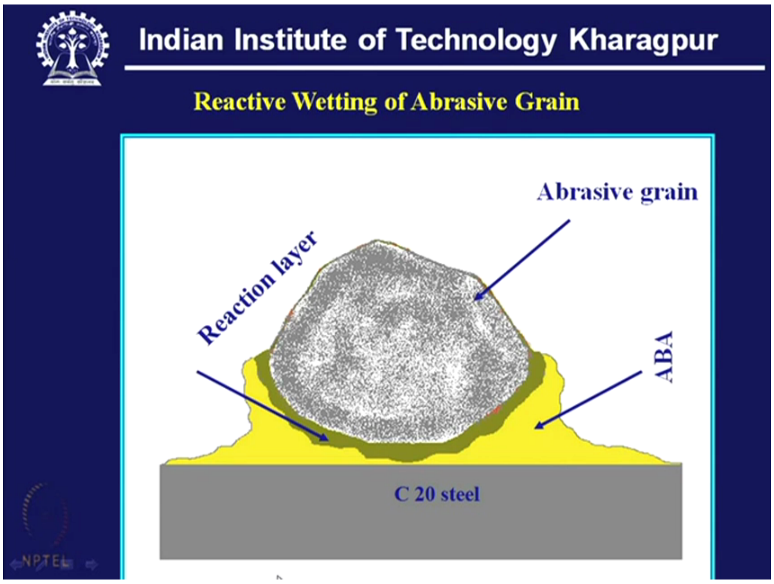


So what is important in this case, very important issue? That as we have mentioned that this is reactive wetting it's no more non-reactive wetting. So here we must have a reaction layer and that has been shown by this schematic figure that say this is one abrasive grain may be diamond or cBN and this is a low carbon steel substrate and this green is held over this steel substrate.

However in between this is the active brazing alloy which can go to a chemical reaction with this abrasive material and the result would be the formation of a reaction layer at this point. Now if it is cBN that means boron and nitrogen very much there and if we use say for example one alloy this bonding alloy which is silver, copper with addition of titanium as an reactive material than what is going to happen?

This BN plus titanium that will lead to TiN and $TiB_2$ that means the surface of the cBN which, if it is a smooth or featureless surface after this reaction if one removes this whole thing this area by proper etching, chemical etching than the surface will reveal itself but it will not be any more that cBN but there will be a reaction layer and it is obvious that this thickness of the reaction layer that can influence the quality of this brazement of braze joint.

We have already discussed this issue that this thickness of the reaction layer whether it is grit material or a bulk ceramic that must be a reaction but this reaction should be confined to a very narrow zone. So a reaction should occur but thickness of the reaction layer should be as small as possible. So this point should be also considered in this particular issue.

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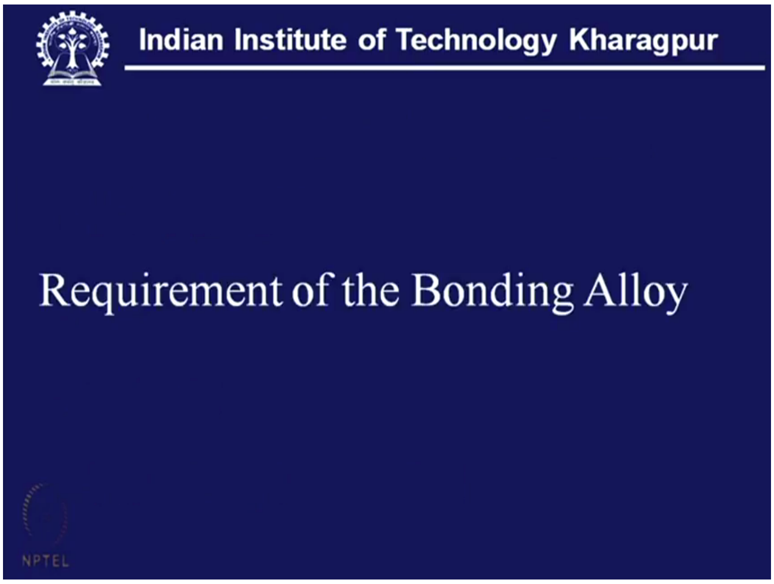


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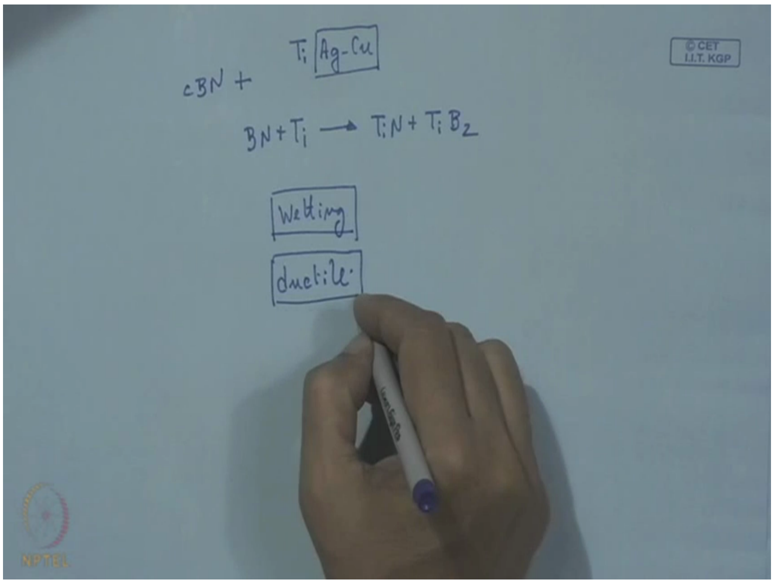


Now requirement of the bonding alloy, now what are the requirement of the bonding alloy? Obviously it should be wetting number 1; the necessary condition that is the wetting, the material must be also ductile. This ductility is also one important term in that, unless the material is ductile there will be tremendous amount of thermal stress. At this brazement it is because of the simple reason that ceramic though it is very small it is cBN and on that other side we have steel.

And in between the bonding alloy which is the braze alloy, so Alpha E, this alpha E and alpha E that means thermal expansion coefficient and young modulus these are varying widely. So one should be flexible enough to adjust itself, so that this difference can be adjusted through this deformation of this braze alloy otherwise cBN cannot be deformed, steel is also not that easy.

So we must have a soft alloy that means having ductility and it is also one of the important factor then basic strength of the material, it should also have certain strength so that under the action of the force the material should not undergo plastic deformation. If it undergoes plastic deformation then the whole purpose will be lost, purpose of brazing because there will be some grinding force and because of the grinding is there be some rise of temperature then at the temperature material strength should be sufficient not to allow large deformation.

So that should be within the control limit. So it is also the strength holding that is also one of the important issue and another thing, so strength comes and more importantly wear resistance.

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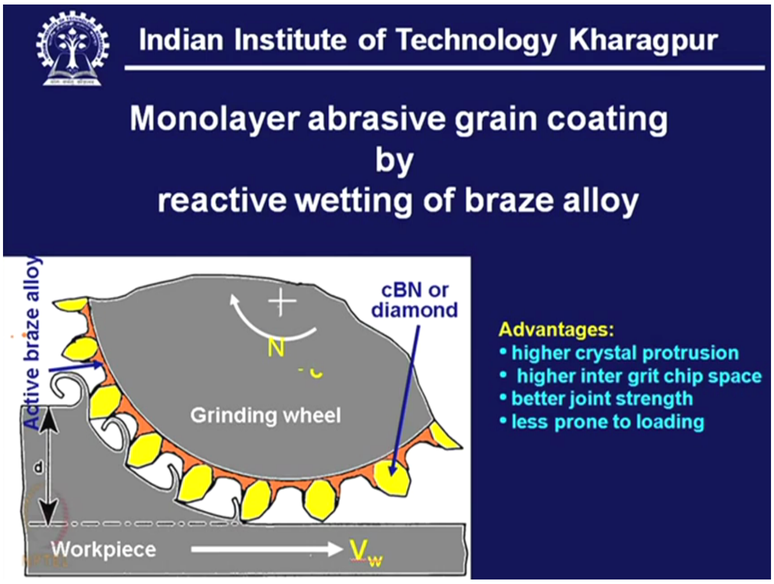

If we get back to this figure quickly, here what we can see? That this chip is sliding and this will, obviously it's expected normally it will slide over the surface. Now the surface should have some kind of tribological quality that means either the friction or wear resistance it must have a good value of this friction coefficient or wear resistance. So that it should not also wear out too fast and if it wears out then there will be fallout of this material. So these 4 properties, this bonding alloy should have but at the same time this wetting, what is this wetting? What does it mean?

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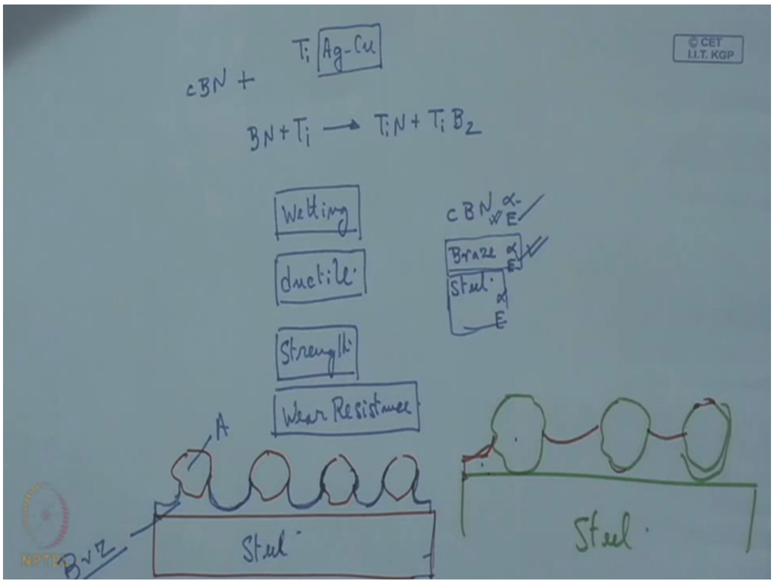


Suppose we have this grit material and this is the bond material, the steel substrate. So the braze alloy should have a balanced wetting towards the steel and also towards the grit. If there is not this balance then the interfacial tension, if there is too much difference in interfacial tension.

If interfacial tension between this braze alloy and this steel is high and with the braze alloy and the grit is low then the whole material will be pulled and you can have accumulation of the material which will be pulled from the place around this grit and bond it will be excessively large, so the whole purpose of brazing will be also again lost. So but if we have adequate wetting on steel then perhaps we can expect to have a profile, something of this form.

So here we can have something of this form, so here we have good wettability of this alloy towards the steel that is the base and this is the abrasive and that is the braze alloy that means the bonding alloy. So it will have very good wettability and it can give a supporting wall over the entire surface of the grit and thereby reducing also the bond level in the space between the crystals.

So good wettability towards the steel and also good wettability towards the grit both characteristics this bonding alloy should show. Now requirement of the substrate material obviously the substrate steel, if it is steel, it should be such that as we have already mentioned that braze alloy should have good wetting over this and another requirement of the substrate is that, it must also have adequate strength, rigidity.

And since in the brazing we have little high temperature, so the distortion or change in shape because of this rise and fall of the temperature at certain level that should be taken care of the material, so that it doesn't crosses its limit of distortion and otherwise this brazing cannot be accepted as a process for making grinding wheel.

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Now comes the brazing parameters. Now what are those brazing parameters? Number 1, precisely the brazing cycle. So brazing cycle we can consider this is the time and that is the temperature. So here the rate of heating then soaking and then it can go like this and this is the holding at that brazing point and then it comes like this. So the entire thing and it almost comes to room temperature. So this whole thing we call a brazing cycle.

Now here this rate of heating then soaking at a temperature just below the liquidus temperature of the material that is very important to have uniformity. Now when it is a geometrically symmetrical in that case problem is not that complicated but if we have a complex geometry then rate of heating in steps and holding in various steps to have proper soaking that means to make the temperature throughout the entire mass uniform that is also one of the very important consideration.

And this waited region can be brought very close to the liquidus temperature and holding there, so that the uniformity of the temperature over the entire mass can be ensured and then thereby quickly raising this point to that brazing temperature and holding there for a very short period of time that is also important.

Now here this temperature of brazing, time at temperature these are the 2 very important parameters apart from that what we also see that environment whether it is inert? Inert atmosphere or whether it is a reducing atmosphere or high vacuum atmosphere that also to be taken into consideration. Now one thing should be also mentioned here that it is a active brazing.

Now the active brazing means one of the reactive material should be present in that metal or alloy. So it is a metal or alloy or it is a metal and alloy, reactive metal and alloy and this reactive metal what should be the amount of this one that is also very important? What we want here? We want a wetting only, only to have coverage over this wall of the grit this is ideally the brazing.

So to have this, what is important to know? The fluidity of the brazing material or the bonding alloy and that depends upon the basic constituents whether it is metal or alloy plus the amount of this reactive element which is present that should be also taken into consideration. Say if we are interested in diamond, what is our experience? That chromium can be used as one reactive element in nickel phosphorus or nickel boron silicon system.

So this is a quite affective alloy to get this kind of profile with diamond the reason is that this chromium can react with the diamond surface making chromium carbide. So this carbon and chromium that goes in this direction maybe $Cr_7C_3$ one of the carbide and here this Delta G is negative. So reaction proceeds in this way and this nickel will wait.

So we can get such a profile with such kind of alloy and the desired profile we can have but when it comes to cBN, so in that case we have to write this one with chromium but this reaction does not move in this direction and hardly we can achieve such profiles that means this kind of alloy is not at all wetting, the surface of boron nitride.

Now here one should look for how this chromium nitride or chromium or it can form. Now we have to look in the change in free energy. Now for brazing we must have a temperature limit of technical interest and if it is within 1000 degrees Lower it is always better but if we consider a limit of 1000 degrees, it is shown that at 1000 even at 1000 this wetting of this alloy either chromium nickel phosphorus or chromium nickel boron silicon that alloy, this wetting is not possible in this case.

So here we see that the free energy of boron nitride is higher than that of chromium nitride or chromium boride but when it comes to when we take a alloy which is readily available, titanium-silver-copper that can be many versions or many formulation this is one of the basic and here we can see that this carbon of diamond and titanium goes straight to TiC formation, this is wetting is perfect with this alloy.

Also be boron nitride less titanium we can also have TiB2 and TiN, of course here hypostoichiometric layer should form on the outer surface but the basic thing is that this TiB2 and TiN which are more stable than boron nitride, so here we have a Delta G minus this one also Delta G minus. So this way one can look into that the severity of the reaction the degree of reaction.

So this amount of reactive element and also it as we mentioned that the existence of the Ternary element reducing the solubility of this reactive element thereby increasing its activity reducing the concentration requirement of this reactive element, all these issues are taken into consideration so that finally what we can achieve?

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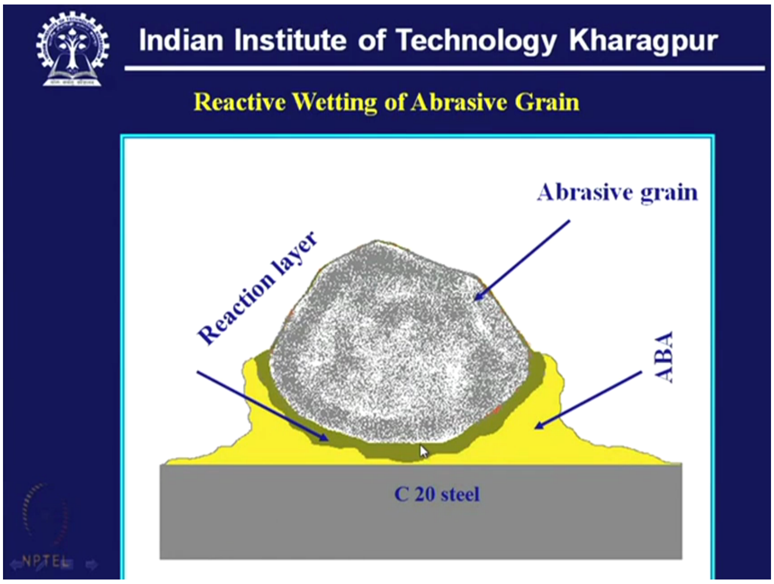


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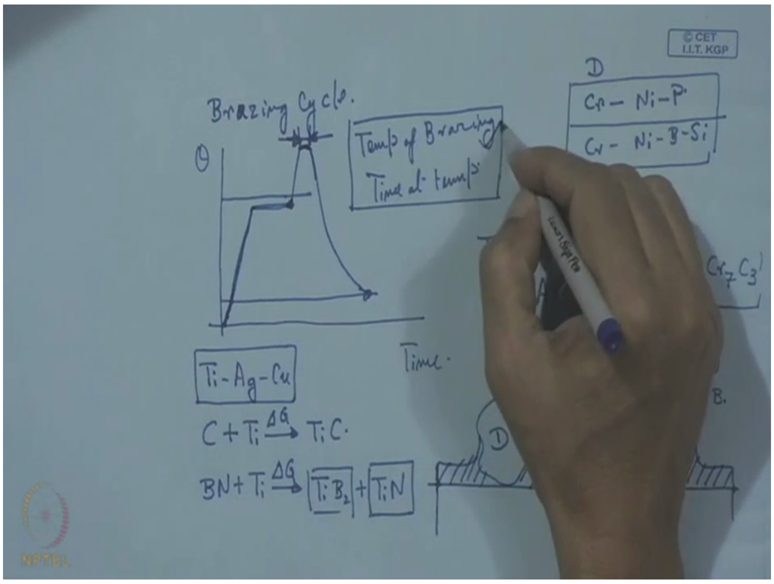


This one we get back to the slide that means this thickness of this reaction layer that can be properly controlled. So in summary what we can say? That this thickness of the reaction layer should be controlled by this brazing temperature number 1 and number 2 by the amount of this reactive element and the presence of one of the ternary element which can control in a very favourable manner that the of this reactive element.

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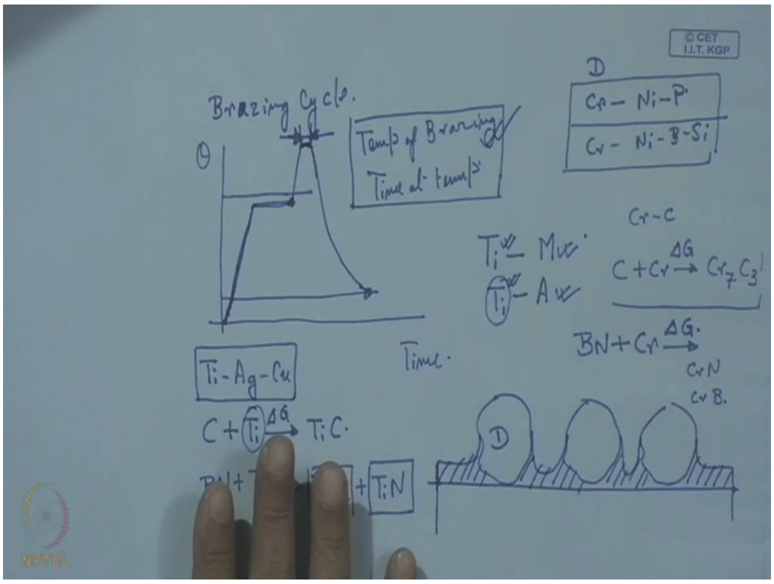


Now here we see the different levels of bonding. So if it is very high temperature the grits are totally covered and this is not a very desirable situation and in one case we can have also the brazing quite satisfactory brazing at a temperature as low as 720 holding these grits and in another case these has to be elevated to 800 degree centigrade and in all cases what we find that it is actually the amount of this reactive element and also the melting point or liquidus point of the brazing alloy or the presence or absence of this ternary element which regulate the activity of this reactive element in the alloy.

And all this will make this difference which are illustrated by this and obviously if it is one passive alloy and there is no chance of wetting and this passive alloy what can be interesting?

That this passive alloy it cannot wet the surface of the steel either. So the existence of titanium or presence of very titanium is so useful, affective also to have wettability over the steel.

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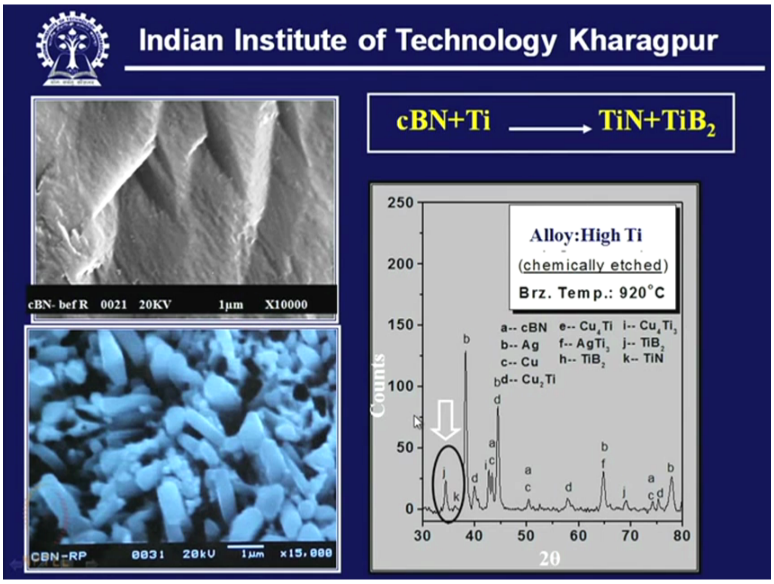


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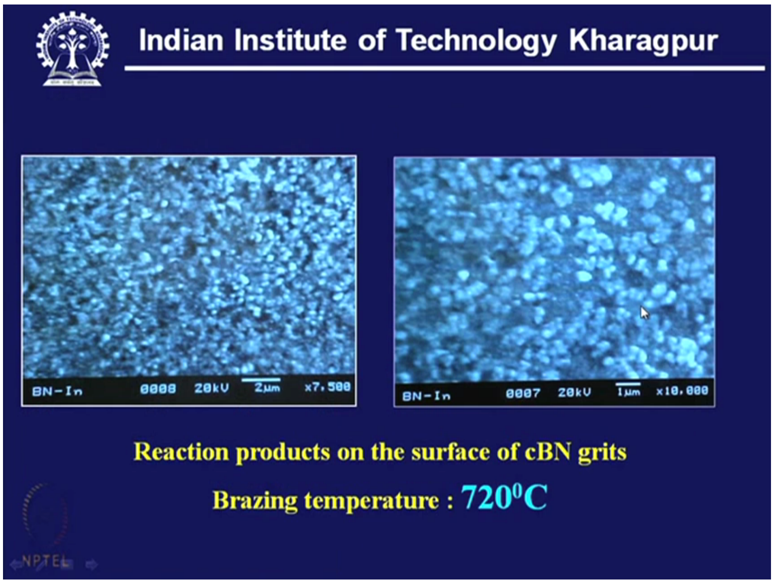


So here we see that this is the very strong reaction showing this needle like thing titanium di boride and it's a very strong reaction with a alloy having almost 10 percent titanium and temperature 920 degree whereas when it is at 720 we have this reaction but it is a mild reaction thickness is also very low and it is good enough to have a very good wetting but at the same time having an adequate bond which is guaranteed by this thinness of the reaction layer.

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Now this is the outcome of this brazing that where the grits are implanted or bonded to the surface and it is actually the coating that means it is a coverage of the grit on this wheel surface in a monolayer formation and is written be located at a fixed distance thereby we can also maintain the gap between the grits, this is desirable from the requirement of grinding.

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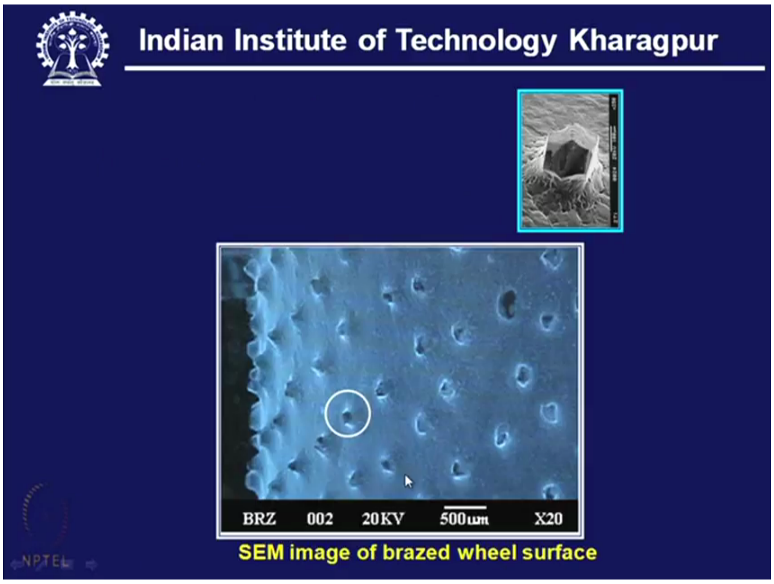


So this is the actual profile of the grit which is bonded and this is the coverage of this grit over the surface. Now in this brazing technique, what is in essence effectiveness? That the concentration of the grit can be adjusted according to the need of the grinding, if it is large material removal rate we can increase the integrit spacing but if it is more wear resistance, precision grinding, high surface finish we can also reduce this spacing and it can be done by this screen printing technique that means temporary fixation of the grit and then by this law of wetting, a surface of this metal can be immediately realized.

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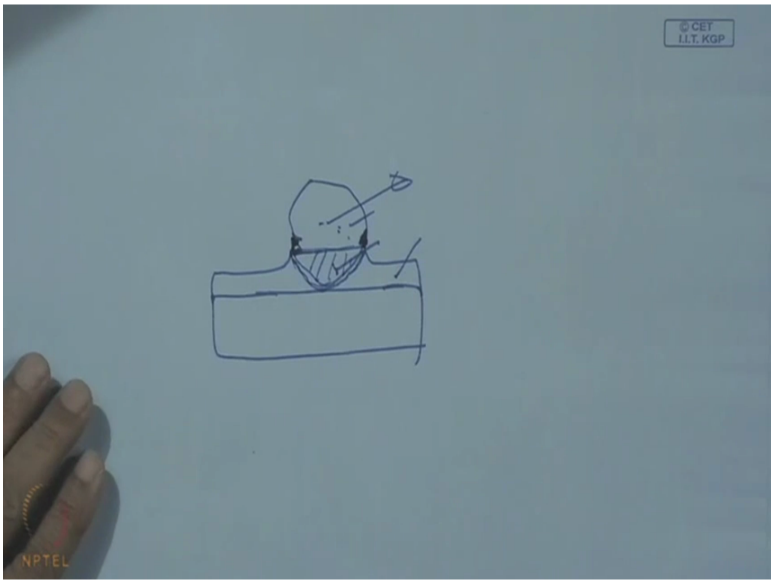


So this summary, what is also important here to know? That though this grit is brazed and apparently there is effective wetting, satisfactory wetting and thinness of the reaction layer that is also ensured here. However what we can see? Here that because of this contraction at this point that maybe a crack formation and this contraction depends upon the relative young modulus, coefficient of thermal expansion and also the liquidus temperature which is also very important parameter which can affect this crack formation.

So there adequate attention has to be paid otherwise what will happen even after getting adequate bonding good chemical attachment because of the generation of the thermal stress this grit can have a break age at this bond level. So this is coverage of the bond and because of this crack formation this part can be removed just because of this thermal cracking.

So with all this thing taken into consideration we can summarize the discussion of today's that high performance abrasive tool can be manufactured by brazing super abrasive grit on metal substrate a monolayer configuration. Effectiveness of brazing depends on wettability of the bonding alloy towards the abrasive as well as the substrate. Besides relation on the brazing cycle is also an important step. The brazing process of course facilitates control of grid spacing and great protrusion on the tools surface.